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# VESTIBULAR SICKNESS AND SOME OF ITS IMPLICATIONS FOR SPACE FLIGHT*

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# VESTIBULAR SICKNESS AND SOME OF ITS IMPLICATIONS FOR SPACE FLIGHT

The advent of manned space flight has posed problems centering around the unique gravitational inertial force environments to be expected aloft, including prolonged exposure to weightlessness or a constantly rotating environment if it is decided to generate an artificial field force by causing the vehicle to spin. It is essential that no one be sent aloft who will be handicapped by functional symptoms arising out of exposure to these force environments, and this presents a far more rigid requirement than has had to be met hitherto.

The dual purpose of this report is to summarize some of our recent investigations dealing with functional disturbance of vestibular origin and to point out their relevancy to manned space flight. These studies have been planned in the light of background knowledge of the vestibular organs[1-8] and their relation to motion sickness,[9-16] but differ from most studies in the past in the fuller exploitation of a constantly rotating[17,18] or counter-rotating environment[19] and the use of subjects with vestibular defects. The report falls mainly into two parts, the first dealing with the symptomatology resulting from brief exposure to different force environments, the second part with the time course of the appearance and disappearance with prolonged exposure in the Slow Rotation Room (SRR).

## EXPERIMENTAL SUBJECTS, FORCE ENVIRONMENTS, AND PROCEDURES

### Subjects

One of our most valuable assets is a group of deaf persons with bilateral labyrinthine defects hereafter termed L-D subjects. The clinical findings in our main group of eleven are summarized in Table I. Some are instructors in schools for the deaf and others are students or graduates of Gallaudet College. It is noteworthy that two give a history of mild motion sickness under a specific circumstance. One suffers from acrophobia, five have residual hearing at high noise levels, one may have minimal residual function of the canals, and one other may possibly have residual function.

An attempt[20] was made to evaluate the functional status of the otolith organs. The counterrolling index, calculated as one-half the difference between the greatest mean right and greatest mean left torsion, ranged from 53 to 176 minutes of arc, while in one of our groups of normal subjects it ranged from 286 to 465. The results of a second test of otolith function, based on the oculogravic illusion, are described elsewhere and reveal some overlap with the normal range and greater individual variance than was true for counterrolling. Although the full significance of these findings is not known, the likelihood exists that some of the L-D subjects have residual function of the otolith organs. This is supported by the findings in the case of a medical student, aged 22, who had suffered an injury to the right ear as the result of a fall when four years of age. Our attention was drawn to his case when he failed to experience symptoms of vestibular sickness in the SRR at 20 RPM. He had no complaints, was not limited in sports or under any handicap of which he was aware. Hearing was much reduced in the right ear, and the caloric test revealed no response to irrigation with cold (about 4° C) water. The counterrolling index was 164, which was below the value obtained from one of the L-D subjects. The important point is that this subject with normal hearing in the left ear and a normal response to caloric stimulation almost surely had normal otoliths.

Normal subjects fell into three main categories, designated "regular subjects," "student subjects," and "aviators." The regular subjects were young men in their late teens or early twenties assigned to the laboratory for the express purpose of participating in experiments. Some of these subjects had never experienced motion sickness prior to this assignment, and advantage was also taken of their unsophistication. The student subjects consisted of men who had finished one, two, or three years of medical school and had been assigned as summer residents with the rank of Ensign. All of the subjects in these two groups were healthy and free from vestibular defects as determined by audiometric and caloric tests and in most instances by the counterrolling and oculogravic tests as well. The third category consisted of flight students, naval aviators, or test pilots, all of whom were healthy and had normal hearing. Some participated in screening or susceptibility tests, and functional tests of the canals and otoliths were not carried out. Those used in investigative studies were carefully tested with respect to function of the semicircular canals but not always with respect to the otolith apparatus.

## Force Environments

Man's gravitational inertial force environment[21] has its genesis in gravity due to a central field factor and the accelerations man experiences as a result of change in velocity or direction of motion. It is the force to which man has become adapted throughout his evolutionary development and to which he is accustomed through experience. Change in position of the body with respect to gravity introduces dynamic effects similar to those if the direction of gravity has changed with reference to man.

Experiments in a rotating environment were conducted in the SRR, which has been described in detail elsewhere. The angular velocity ranged from 1.0 RPM to 20.0 RPM. There were a number of important advantages in using the SRR. The angular velocity could perfectly simulate angular velocities which might be used aloft even though certain aspects of the two force environments were different. The level of stress covered a range at which the most susceptible persons were practically symptom free, and at the other extreme the least susceptible with one or two exceptions could readily be made sick. A third great advantage was having an experimenter with the subjects. Long-term experiments, including studies of adaptation, were possible because the size of the room allowed adequate space for housekeeping facilities. Finally, the stimulus to the semicircular canals, Coriolis acceleration, was under absolute control insofar as it was generated only when the subject's head moved out of the plane of rotation of the room. Near the center of the room the magnitude of the force stimulating the gravireceptors, including the otolith apparatus, was very small.

The so-called dial test was used to standardize the stress a subject experienced. The subject was required to set the needle on the dial at a given number, on signal. The dials were so placed in relation to the subject when seated that he was required to move the head and trunk to five different extreme positions which maximized the Coriolis stimulus to the canals. A sequence consisted in setting five dials, one every six seconds, followed by a six-second rest period. In screening tests the subject was requested to complete four sequences but at other times as many as twenty.

Experiments utilizing the counter-rotating room were conducted in the vestibular facility at the Canadian Defence Research Medical Laboratories in Toronto, Canada. This room consisted essentially of a secondary turntable mounted on a centrifuge of short radius and which, by means of a direct mechanical linkage, always revolved at the same rate as the main centrifuge but in the opposite direction. The subject, therefore, was not exposed to angular velocity except that which might be generated by his own movements. This device had the double advantage of allowing the experimenter to prevent any stimulation of the semicircular canals while at the same time the gravi-receptors, including the otolith apparatus, were subjected to an unusual pattern of stimulation. Exposure under these conditions might have relevancy to exposure to weightlessness in that the inputs from the semicircular canals were similar and presumably normal, and the inputs from the gravireceptors, including the otolith apparatus, were unusual.

This device has many of the advantages of the SRR, but with the use of a two-foot radius the magnitude of the forces was not great even at 30 RPM, and many subjects were not stressed to the point where significant symptoms were perceived or displayed. In an effort to exaggerate the symptomatology, the subjects were requested to rotate the head in different directions in random fashion and upon occasion they were requested to wear glasses containing $15^{\circ}$ prisms.

Some use was also made of the force environments generated by a C-131 aircraft during Keplerian trajectories,[22] by an A-1E (AD-5) aircraft which exposed the subject to standardized aerobatic patterns for thirty minutes, and those generated at sea in a small boat.[23] Standardization of the force environment generated by the small boat was impossible although an attempt was made to do so. Also lacking were the great magnitude of displacements of a large ship in a heavy sea and their effect on the visual and force environments.

Factors Other Than Force Environment. These fell into two categories: 1) nonforce environmental factors such as visual framework, noise, odors, atmosphere, living space, social factors, et cetera, and 2) the state of anxiety, alertness, health, and motivation of the subject. These factors were either taken into account or manipulated in a different experimental investigation.

## Procedures

No attempt will be made here to describe the apparatus used, inasmuch as this has been done elsewhere. However, it is worthwhile to mention briefly our experience in the development of case report forms which have rather general applicability. These are undergoing constant revision and will be discussed mainly in terms of the purposes they serve.

One is a four page "motion sickness" questionnaire with open-ended features. It attempts to identify and quantify the subject's past experiences under 1) experimental circumstances, and 2) nonexperimental conditions in which he has been passively exposed to different force and visual environments. A second category emphasizes activities in which he was an active as well as a passive participant. Provision is made for expressing pleasurable as well as unpleasurable reactions and experiences. He is forced into rating himself, not only on an absolute basis but also with reference to others. The examiner is expected to rate the subject as to whether his experience has been adequate or indicate that the rating is made with a reservation based on the extent of the subject's past experience.

A set of forms has been prepared, one or more of which is now used in connection with every experiment. The first form is termed the "subject's pre-experimentation interview," with open-ended features for the purpose of determining if the subject is fit for participation. This covers not only his medical status but his physical and psychological fitness as well. The experimenter is forced to rate the subject as 1) unfit to participate for reasons of health, 2) fit to participate but the results cannot be used in the designed experiment, and 3) fit to participate and the results will be used in the designed experiment. The subject is required to indicate the degree of his concern over the forthcoming experiment and how he expects to perform in comparison with others.

Two forms have been prepared for the use of the experimenter alone, one centering around the period he observes the subject undergoing the stress, and the other centering around the recovery period following the test. Somewhat similar forms have been prepared for the use of the subject, although his experiences during exposure may have to await the end of the experiment.

## CLINICAL SYMPTOMATOLOGY IN L-D SUBJECTS UNDER EXPERIMENTAL CONDITIONS

In Table II are summarized results in the 11 L-D subjects when exposed to the maximum stress under five different experimental conditions. In no instance did they experience symptoms characteristic of motion sickness. The sweating they felt was never associated with pallor and was due either to the high environmental temperature or to the fact that considerable physical work was involved. The subject with acrophobia was extremely nervous prior to the aerobatic flight and stated afterward that it took much fortitude to enter the aircraft. He did experience symptoms of anxiety aloft, and this was reflected in an increased excretion of urinary catechol amines, especially epinephrine. In the SRR rotating at nearly 20 RPM, the subjects were required to set the dials while exposed to a centripetal force ranging from 0.56 to 0.84 G. In the CRR they were required to rotate the head to different directions while experiencing a centripetal force of 0.61 G for a period of thirty minutes. Their complaints under these circumstances were minimal.

It is worth noting that the two subjects with a history of slight motion sickness never experienced similar symptoms under the experimental conditions. In both of these subjects, the illness which gave rise to their vestibular defects occurred at the ages of 12.5 and 13 years. An unsatisfactory attempt was made to determine if this history of motion sickness had its onset prior to this age. In sharp contrast to any of the groups of normal subjects, nearly all took pleasure in the experiments. The few comments in the table do not adequately express their obvious desire to participate, the pleasure which could be read in their faces, and their remarks afterward. In the case of the field experiments, and especially in connection with the C-131 flights, some would sit in the ready room, waiting for an opportunity to go aloft on a space available basis. One subject after completing a trial at maximal speed in the CRR wrote that it was "like driving a boat in rough seas because my head was free to roll with the waves. Exhilerating - I wanted to step on it and go faster much as I do when driving or boating when I am alone."

The one important point of similarity between the L-D and normal subjects had to do with the visual but particularly the postural illusions experienced. Quantitative measurements were not made in these five different experimental situations, but some of the L-D subjects described visual illusions closely resembling those described by normal ones, and most of the L-D subjects described postural illusions in the CRR, where they were most readily perceived, which were quite similar to those described by normal subjects. Stated differently, stimulation of the nonotolithic graviceptors in the L-D subjects gave rise to the characteristic postural illusion in the CRR indicating that, except for lack of hearing, their sensory input reaching the level of awareness did not differ greatly from that experienced by normal subjects. If the assumption is made that the 11 L-D subjects are representative of their kind, the generalization can be made that all or nearly all motion sickness is indeed vestibular sickness. Some investigators have expressed the opinion that only a percentage of subjects with vestibular defects are free of motion sickness. Certain reasons for these differences in findings might be responsible. If, for example, the vestibular defects had been acquired late in life, symptoms of motion sickness might have persisted as a conditioned response. Moreover, symptoms of motion sickness and psychoneurosis may be almost indistinguishable, especially in mild form, and symptoms resulting from nociceptive stimulation may be similar to those in motion sickness.

Until our L-D subjects have been exposed to severe stress at sea, some reservation must be made as to whether they can experience motion sickness. Not only has the characteristic of the motions of the ship at sea etiological significance in causing seasickness but also the magnitude of the movements, with consequent effect on the visual and force environments.

## CLINICAL SYMPTOMATOLOGY IN HEALTHY SUBJECTS UNDER EXPERIMENTAL CONDITIONS

For convenience in description, an attempt has been made to grade the severity of vestibular symptoms as shown in Table III. There is quite general agreement with regard to the major symptoms, but there is room for disagreement with respect to the diagnostic terminology.

The statements of a subject regarding his subjective symptoms are obviously not based on the same yardstick. To some extent, this limitation may be offset by an attempt on the part of the experimenter to take into account the concordance between the objective and subjective symptomatology. But even the use of this device presents its own difficulties. For example, a subject may complain of moderate or even severe nausea, at the same time exhibiting neither pallor nor sweating. The great likelihood here is that his report represents an exaggeration of the severity of the symptoms, but the examiner is faced with great difficulty in any attempt to challenge it. The other extreme is represented by subjects who exhibit moderate or even severe pallor and sweating, yet declare they are not nauseated. In most instances, one may accept this report, but exceptionally a subject may not wish to admit that he has nausea, with the thought in mind that it reflects on his fortitude, but he may readily admit to having "stomach awareness," a term which we have found very helpful.

The distinction between cold sweating, thermal sweating, and sweating primarily due to anxiety may present difficulties. Even if one takes into account the atmospheric conditions, the regions where sweating appears, and such things as the associated flushing or pallor, it is still possible to be in error, or indeed the sweating may very well be due to more than one factor.

In some instances we have observed symptoms which justified an additional diagnosis of vestibular psychoneurosis. This was suspected when the individual had many subjective complaints under minimal stressful conditions. These subjective symptoms were out of proportion to the associated manifestations or even appeared in their absence. Another characteristic was the fact that the subject continued to complain for an unusually long time after being relieved of the stress. Even more specifically, the subject might complain of decreased rather than increased salivation, of normal or increased alertness rather than drowsiness, and manifest aerophagia, characteristic facies of anxiety, and the hyperventilation syndrome.

The clinical symptoms in nine regular and nine student subjects are summarized in Table III, and the subjects are ranked according to their history of nonexperimental motion sickness. Of the eleven subjects without a history of motion sickness, the first eight had not been exposed to many unusual force environments, hence, the negative history was not necessarily a good measure of their susceptibility. Three of the eight became sick during aerobatics, and the remaining five did not wish to volunteer for the flight. FO was less susceptible than the average to exposure in the SRR and was asymptomatic in the CRR. ME became sick in the CRR, while TO became sick in the SRR but was asymptomatic in the CRR. The remaining three subjects, SA, PA, and RE, could be classified as "insusceptibles" under all of the conditions to which they were exposed.

The seven subjects with a history of motion sickness all became sick under one or more of the experimental circumstances, and four of the seven, who had a history of far above average susceptibility to motion sickness, were either sick under all conditions or the experiment was terminated at a very early stage. For example, one subject wished to terminate the experiment in the SRR before he had set a single dial.

The most remarkable instances of the appearance of symptoms under minimal stress occurred in the CRR. At 10 RPM the subjects were exposed to a centripetal force of less than 0.1 G and were barely aware of the changing relationship, feeling of tilting as they rotated, inasmcuh as the angle phi was less than four degrees. Two of our subjects experienced symptoms under this circumstance, and one asked to have the experiment terminated after fourteen minutes. One other subject, not shown in this chart, complained even before the room was set in motion. Subjects exposed to rotation in the CRR included some with an extremely high susceptibility to vestibular sickness, and they experienced no unpleasant symptoms at velocities of 15 RPM and below.

In comparing the symptomatology in the healthy subjects and those with labyrinthine defects, the following comments are to the point and may be noted. Symptoms precipitated by exposure to unusual force environments are to be attributed directly or indirectly as originating in the vestibular organs. Great individual variance in susceptibility is observed in an unselected group of healthy subjects; the tendency is for them to be divided into susceptibles and insusceptibles. The symptomatology in the insusceptibles tends to be typical and that of the susceptibles atypical. The atypical symptoms are mainly of a psychoneurotic nature and, if of considerable severity, may appear when the force and nonforce environmental factors are not stressful. Exposure to unusual force environments reveals important individual differences with respect to willingness to undergo such stress and the readiness with which they complain under stress.

## SIGNIFICANCE OF THE EXPERIMENTAL FINDINGS IN CRR COMPARED WITH SRR

In the CRR, with head fixed, stimulation of the canals did not occur, and the symptoms experienced by healthy subjects were precipitated by the centripetal force at the incident angle phi which constantly changed its geographical position in respect to the subject through 300° with each revolution. Gravireceptors including the otoliths were stimulated in an unusual fashion and must have acted as the chief precipitating factor. It is of interest in this connection that in

Wendt's experiments wherein he exposed subjects to rectilinear accelerations, thus avoiding stimulation to the canals, some of his subjects did not become sick under the most stressful force environments which could be generated.

It is possible to distinguish between the roles of the otolithic and non-otolithic receptors only if the canals are not taken into account, an obvious disregard of "intervestibular conflicts" and the role the vestibular organs together have played in the past. Nevertheless, it is a clearly cut instance of the precipitation of vestibular symptoms in the absence of stimulation of the canals and demonstrates that an unusual input from the otoliths (and nonotolithic gravireceptors) may give rise to functional symptoms. "Otolith sickness" might be a helpful designation to identify symptoms under this or similar circumstances.

The effectiveness of the stimulus in the CRR is heavily dependent on the magnitude of the force. This suggests but does not prove that the de-afferentation in weightlessness which also leads to an unusual input may not be a severe stress because of the absence of a "magnitude of force" effect.

Symptoms were more readily precipitated in the SRR than in the CRR, although it cannot be assumed that the stresses, measured in terms of per cent of the maximum possible stress, were comparable. When the subject is near the center of rotation in the SRR, the centripetal force is small and the

Coriolis force is mainly a consequence of the angular velocities of the head and room. If an unusual stimulus to the otoliths with the bodily rotation limited to the head is assumed, the magnitude component would be small and of relatively little significance compared with the input from the canals. Elsewhere[24] reasons have been given for justifying the term "canal sickness" when the chief precipitating factor has been the unusual stimulation of the semicircular canals.

## PROLONGED EXPOSURE IN A CONSTANTLY ROTATING ENVIRONMENT

These experiments fell into two main categories, namely, observations on the time course of the appearance and disappearance of symptoms, and the investigation of specific symptoms or mechanisms.

### General Adaptation

Subjects were exposed to constant rotation for approximately two days at 1.0, 1.7, 2.2, 3.8, 5.4, and 10.0 RPM and for two weeks at 3.0 RPM. The subjects were selected mainly in terms of their susceptibility to vestibular sickness and, in retrospect, our early evaluations proved to be poor inasmuch as we did not properly take into account the fact that our regular subjects had not been exposed to sufficiently stressful force environments. The subjects were urged to limit their activities involving head movement to avoid severe nausea or vomiting. In addition to housekeeping activities, they were required to carry out a number of specific tasks and tests, including the dial test.

GR, one of the subjects with bilateral vestibular defects, was a participant in all of the experiments except those at 1.0 and 3.0 RPM. He had no complaints, and the only significant change in the symptomatology was difficulty in walking. This was not evident at 1.7 or 2.2 RPM but it was manifest, according to the inside observer, at 3.8 RPM, although the subject stated that he had no difficulty. On cessation of rotation at this speed, he reported no aftereffects, and he had no difficulty in walking heel-to-toe. At 5.4 and 10.0 RPM he had significant difficulty in walking to which he readily adapted at 5.4, but more slowly and less well at 10.0 RPM. Following rotation at 10.0 RPM, he experienced greater difficulty in walking than during the control period.

With regard to the normal subjects, there was a progressive increase in severity of symptoms with increasing RPM, if differences in susceptibility were taken into account. At 1.0 RPM symptoms were almost nil in the case of four subjects,[25] two of whom were below average, one average, and one above average in susceptibility. The only symptom manifested was slight difficulty in walking heel-to-toe with eyes closed, to which they adapted. Four additional subjects highly susceptible to vestibular sickness were exposed for a shorter period of time at 1.0 RPM, and the symptoms were negligible. Two had slight malaise following completion of the first dial test but not thereafter. Two of the four subjects perceived the Coriolis illusion during rotation, and all perceived it following rotation.

Three men and an experimenter participated in an experiment wherein they were exposed to rotation for two weeks at 3.0 RPM. With regard to their susceptibility to motion sickness, two were regarded as average and one above average. The one subject with greater than average susceptibility experienced malaise the first day and thereafter his symptomatology was complicated by the appearance of a slight cold. The other two subjects were not handicapped in carrying out their tasks which kept them busy from early in the morning until four o'clock in the afternoon. Either no change or a continued improvement was found in scoring a wide variety of psychological and physiological tests with two exceptions. There was evidence of a decrement in performance in carrying out a mathematics test during the first day of rotation but not thereafter. They also exhibited difficulty in postural and walking tests but a return to the baseline level on the fourth day. Following rotation these difficulties reappeared, but their approximate baseline values were again reached on the second post-rotation day. The conclusion was reached that no serious disturbance of a psychological or physiological nature occurred either during the two weeks of rotation or during the recovery period.

The remaining experiments were conducted as a single series of experiments using the same subjects on more than one occasion.

At 1.7 RPM, two subjects less susceptible than the average to motion sickness, on the basis of their history, experienced slight nausea following the dial test on the first day but not thereafter. Except for difficulty in walking, the other symptoms were negligible and probably related in part to the confinement.

At 2.2 RPM two subjects with less than average susceptibility to motion sickness had different experiences. One complained of slight dizziness and slight apathy on the morning of the first day only and was otherwise asymptomatic. The other subject experienced nausea throughout the run and had vomiting episodes the morning and afternoon of the first day. He complained of other symptoms as well, and, in general, adapted poorly to the stress.

At 3.8 RPM two insusceptible subjects, based on their motion sickness history, also had different experiences. One subject had nausea on the morning of the first day which did not reappear until after he had developed a cold. The Coriolis illusion, to which he had previously adapted, also reappeared following the respiratory infection. The second subject was practically symptom free.

At 5.4 RPM a subject who had been practically symptom free at 2.2 RPM experienced severe nausea and vomiting the morning of the first day with some improvement in the afternoon and with complete freedom from symptoms on the second day. The second subject, who had experienced nausea and vomiting at 2.2 RPM, experienced symptoms throughout the two days. He suffered severe nausea and vomiting both morning and afternoon of the first day, and on the second day the nausea decreased and no vomiting episodes occurred. Some of his symptoms were clearly of psychoneurotic origin. He complained of "tension headache" and the aerophagia was sufficient to cause abdominal distention. He exhibited a sighing type of respiration, and the inversion of the T waves in the electrocardiogram were probably the result of overventilation. This represents a clear example of a complication in the form of psychoneurosis indirectly of vestibular origin.

The two subjects who had performed best at lower RPM were now chosen for the experiment at 10.0 RPM. Both had symptoms throughout the entire period. One had nausea the first day but not the second, although the general malaise and discomfort were greater the second day than the first. The second subject had nausea throughout the entire period, although decreasing on the second day, and there was no vomiting after the first day.

Although he was adapting better than the other subject, he remained apathetic, slept several hours during the daytime, and, in general, gave the impression of declining fitness to carry out assigned tasks.

Many additional experiments have been carried out in which the subjects have been exposed, usually for periods of six to eight hours at a velocity usually of 7.5 RPM. Although the details concerning clinical symptoms were not collected systematically, a few important observations were nevertheless verified: 1) Symptoms were minimized by covering the subject's eyes; 2) the more alert the subject, the faster the adaptation; 3) the greater the degree of activity, the more rapid the adaptation; 4) the more complete the adaptation, the more severe the symptoms following cessation of rotation; 5) considerable individual variance exists in the speed with which adaptation occurs; and 6) the rate of adaptation is different for different subjective symptoms or objective manifestations.

## Mechanisms Involved in the Adaptation Process

Three visual illusions are readily identified in the Slow Rotation Room if the stimulus is adequate, namely, the oculogravic, oculogyral, and Coriolis illusion. It was found that adaptation to the oculogravic illusion did not occur within a four-hour experimental period.[26] Measurements on the oculogyral illusion also revealed little or no change after prolonged exposure at different rates of rotation. Adaptation to the Coriolis illusion, however, was found to occur readily as seen in Figure 1. Moreover, on cessation of rotation, movement of the head which no longer generates a Coriolis acceleration nevertheless gives rise to a Coriolis illusion but with opposite sign. This is interpreted as indicating a conditioned response of a compensatory nature.

When nystagmus is used as an indicator, some subjects also exhibit a conditioned response of a compensatory character. In Figure 2 are shown nystagmograms obtained on the same subject before, during, and after cessation of rotation. It is seen that soon after the onset of rotation an upward beating nystagmus is recorded while thirty minutes to an hour after cessation of rotation, a downward beating nystagmus is registered in association with the same head movement. That this compensatory nystagmus was independent of vision was demonstrated by the fact that it could be obtained with eyes covered; that also it could be obtained with passive as well as active movment of the head indicates that a voluntary movement was not essential.

The same indicators, namely, the Coriolis illusion and nystagmography, have been used in studying the specificity of the adaptation process and its reciprocal, the paucity of transfer effects. If a subject under suitable conditions is required to make head movements in one quadrant of the frontal plane over a period of hours, there is a decline in the Coriolis illusion and the nystagmic response. Toward the end of the rotation period the same head movement in the unpracticed quadrant yields illusory and nystagmic responses of approximately the same magnitude as at the beginning of rotation. On cessation of rotation, head movement in the unpracticed quadrant yields no response.

A rise in threshold of response to thermal stimulation has been demonstrated by Johnson and his coworkers.[27] The rise was evident on the second day of rotation.

Post-Rotation Effects

Few investigations have been carried out adequately covering the full post-rotation period. Two reasons for this have been the desire on the part of the subjects to be free after prolonged confinement in the SRR and the fact that symptoms are not severe except on the first day of recovery. There is evidence, however, that after prolonged exposure to severe stress the control state has not always been reached, even on the second day following cessation of rotation. The systematic investigation of these post-rotation effects will yield findings of theoretical and practical value. Here, too, individual variance is great.

When a person is exposed for only a brief period to intense stress, the post-rotation symptomatology is mainly to be ascribed to perseveration rather than to the appearance of symptoms such as would follow complete adaptation. Here the individual variance is extremely great, and exposure of twenty minutes, for example, may be followed by symptoms lasting into the second day. Systematic studies covering this aspect of vestibular sickness are needed.

Two other related aspects deserve brief mention, namely, the fact that adaptation to one velocity of rotation offers some protection to exposure at higher velocities, and interruptions in exposure to rotation tend to minimize the post-rotation effects. Both these areas await fuller exploration.

## SOME IMPLICATIONS FOR SPACE FLIGHT

Motion sickness may be regarded as having its origin directly or indirectly in the vestibular organs, and vestibular sickness is the more meaningful term. It is nearly always precipitated by exposure to an unusual force environment, and qualitative and quantative variables are both important as are such factors as the duration of exposure, the periodicity, or the pattern of waxing and waning of stimulation. Additional precipitating factors may be found in the nonforce environment, and intrinsic predisposing factors may be fundamental or relatively constant and superficial or relatively temporary. Much remains to be learned regarding central nervous system mechanisms concerned in the causation of vestibular sickness and its disappearance through adaptation.

The functional symptoms of vestibular origin vary greatly in kind and severity; mild syndromes may not be recognized as such, and complicating disorders especially of a psychoneurotic nature may not be placed in their true etiological relationship.

Vestibular sickness may be precipitated in the absence of stimulation to the canals. Both the unusual pattern of stimulation and strength of stimulus are of etiologic significance. These findings strongly suggest that even unusual patterns of stimulation would be well tolerated down to a critical level. In the weightless state the absence of the "magnitude" variable may be a factor minimizing the disturbing effects.

Insofar as experience in the SRR may be extrapolated to conditions in a rotating space vehicle, a velocity of 3.0 RPM should not present important problems. A velocity of 5.0 RPM is feasible if adequate provision is made in the areas of initial crew selection, training, and adaptation prior to launch and if provision is made for well-being aloft and pre-descent adaptation. An increase stepwise from 3.0 to 5.0 RPM would greatly minimize the initial effects and the reverse, the post-rotation effects. A velocity of 10.0 RPM presents problems some of which still await solution.

Our experience has again emphasized the need for a most comprehensive evaluation before attempting to grade persons in terms of their susceptibility to vestibular sickness. The reason is partly to be ascribed to meager transfer effects and to the difficulty or impossibility of simulating all the force and nonforce environmental factors under terrestrial conditions. More effort and the desirability of validation studies are evident.

Finally, a comment must be repeated regarding the spectacular freedom from symptoms enjoyed not only by persons with bilateral vestibular defects but, also, at least on an individual basis, by persons with only partial loss of function or unilateral loss. The loss of hearing in one ear might be less of a handicap than troublesome vestibular symptoms. The possibility of preventing symptoms either temporarily or permanently by drug therapy is at least a reasonable hope based upon study of the effects of streptomycin sulphate administration in animals.

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